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President's conference paper

The case for particle therapy

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Abstract. Among the most important decisions facing the British Government regarding the treatment of cancer in the National Health Service (NHS) is the purchase of charged particle therapy (CPT) centres. CPT is different from conventional radiotherapy: the dose is deposited far more selectively in Bragg Peaks by either protons or "heavy" ions, such as carbon. In this way, it is possible to "dose paint" targets, voxel by voxel, with far less dose to surrounding tissues than with X-ray techniques. At present the UK possesses a 62 MeV cyclotron proton facility at Clatterbridge (Wirral), which provides therapy for intraocular cancers such as melanoma; for deeper situated cancers in the pelvis, chest etc., much higher energies, over 200 MeV are required from a synchrotron facility. There is an impressive expansion in particle beam therapy (PBT) centres worldwide, since they offer good prospects of improved quality of life with enhanced cancer cures in situations where conventional therapy is limited due to radioresistance or by the close proximity of critical normal tissues. There is a threat to UK Oncology, since it is anticipated that several thousand British patients may require referral abroad for therapy; this would severely disrupt their multidisciplinary management and require demanding logistical support.

The benefits of an increase in charged particle therapy (CPT) centres in the UK would be not only for children and young adults with cancer, where a reduced risk of radiation induced malignancy is predicted, but also in older patients where it is necessary to avoid abnormal tissues such as an enlarged heart/restricted lung irradiation and where artificial (metallic) joints may cause difficulties in the use of conventional radiotherapy techniques. The results of phase I and II clinical studies are extremely encouraging. The UK must obtain at least one CPT centre with protons/ions in order to conduct research and development; it is suggested that quality adjusted life years should be used to assess outcomes. It is anticipated that the UK might eventually require 7–8 such centres in 10–15 years from now. In the meantime, healthcare purchasers and providers need to put in place mechanisms and personnel for patient referrals abroad, as well as the establishment of UK CPT facilities.

Background

The connection between subatomic particles and health delivery improvements may seem rather tenuous, but the narrative begins in 1879, when J J Thompson discovered the negatively charged electron in Cambridge, and Aneurin Bevan was born in Wales. The subsequent discoveries of the positively charged proton (a term coined by Ernest Rutherford in 1920) and the uncharged neutron by James Chadwick in 1931, confirmed the pre-eminence of our science. Bevan, with similar precision of thought, digested the wide recommendations of the Beveridge Report (1942) and transformed most of its principles to practical achievements, including the National Health Service Act of Parliament (1946) and the inception of the service in 1948. Subsequently, Britain was at the forefront of practical applications of physics and engineering developments in cancer therapy until the early 1990s, when the reorganized NHS became disadvantaged in terms of expensive technological acquisition.

Dr R D Errington related the history of cyclotron radiotherapy at the BIR President's Day conference in 2003. He detailed how the initial promising results obtained with neutron therapy at The Hammersmith Hospital were not subsequently confirmed in randomized trials at Edinburgh and at the Clatterbridge facility [1, 2], which produced neutrons that matched a 5 MeV X-ray beam. The latter facility was converted to produce protons on the recommendation of the late Prof. Arthur Jones of St Bartholomew's Hospital. This enabled patients with choroidal melanoma of the eye to receive radical radiotherapy using protons; this technique was the first example of three-dimensional (3D) radiotherapy in the UK. Over 1400 patients have by now received this therapy with a local control rate of 98% – an outstanding achievement within British medicine [3].

Past attempts to obtain a higher energy facility in the UK

Since 1992, Clatterbridge, Oxford and the National Physical Laboratory at Daresbury (near Warrington) have all unsuccessfully attempted to obtain a higher energy CPT facility [4]. All these bids were rejected because of perceived lack of clinical support, intermittent beam availability, the lack of clinical trial evidence, the recommendation that a facility should be sited in a University Hospital campus and perhaps mostly, the expected high initial costs incurred at a time when NHS reforms discouraged large-scale projects, even the provision of new (replacement) linear accelerators.

More recently, there has emerged a more collective response from clinical oncologists and medical physicists who appreciate that obtaining a CPT facility is essential

for the advancement of radiation oncology standards in the UK. The Royal College of Radiologists (RCR), British Institute of Radiology (BIR) and Institute of Physics and Engineering in Medicine (IPEM) for example all support the case for a CPT facility. Recent improvements in the quality of cancer imaging and the availability of industrially produced turnkey facilities, has allowed the question to be carefully re-considered and better understood, particularly in relation to the rapid expansion in CPT facilities abroad.

Technical aspects

The velocity of heavy charged particles (electrons are considered to be light) is reduced as they traverse deeper through tissues. The interaction probability to cause ionization increases as the velocity falls, so that a peak of dose occurs at a depth proportional to the energy imparted to each particle. William Bragg, a British physicist, described this phenomenon over 100 years ago [5]. The so called Bragg peak can be "spread out" to achieve a plateau of uniform dose that covers a target by use of rotating range-shifting modulators of variable thickness. In the past, passively scattered beams were used in this way to provide wide circular or rectangular beams with spread out Bragg peaks (Figure 1). More recently, the spot scanning method allows smaller beams to deposit their peaks within individual voxel targets defined by good imaging techniques: by the use of "wobbler" magnets and particle energy selection, the raster scanning system allows cancer bearing voxels (defined by *x, y, z*, co-ordinates), to be "dose painted".

The Bragg peak position will depend on the initial energy imparted to the particles as well as their mass and charge; the Bethe-Bloch equation contains all the necessary parameters. It can be seen from Figure 2 that the range for clinical use should be at least 200 MeV in the case of protons; higher energies – up to 400 MeV – for carbon ions.

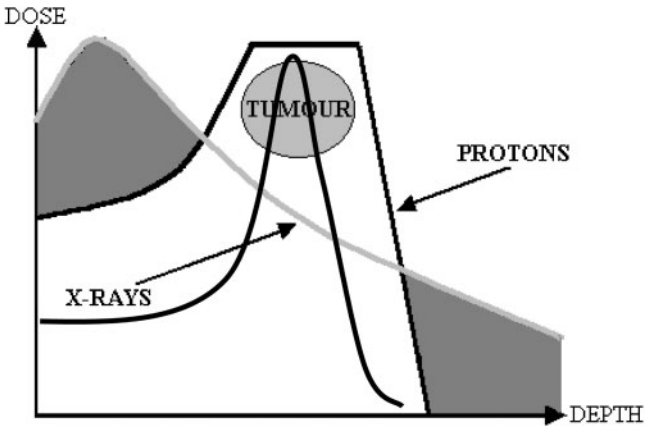


Figure 1. Schematic depth dose diagram of a proton beam Bragg peak, the spread out Bragg peak and a megavoltage X-ray beam (modified from Suit et al [12]). The grey shaded areas indicate the extent of dose reduction within normal tissues situated proximal and distal to the tumour target.

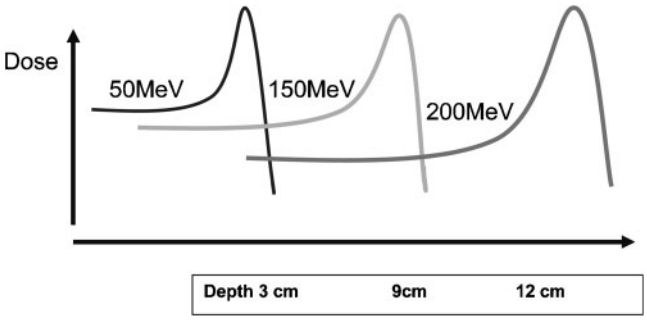


Figure 2. Approximate depth dose positions of partially spread out Bragg peaks for protons of different energies.

Gantries and robots

Within treatment rooms there are options for beam arrangements. The simplest approach is to have either fixed horizontal or vertical beams, or a combination of the two for the simplest treatments. An isocentric rotating gantry is required for more complex geometrical problems. These consist of large cylindrical rotating structures that contain the beam bending magnets: they weigh 100 tonnes for protons and 200 tonnes for ions and require movement with 1 mm precision of beam placement. Future engineering innovations may reduce the tonnage and costs. Robotic treatment couches are desirable in order to rapidly position the patient at predetermined angles relative to the beams; they may also transport patients in fixed positions from image guided or other localization devices in the treatment rooms to the actual treatment location. Radiographers may feel sensitive about robotics, but it will always be the radiographer who commands the robot and remotely monitors their performance.

Typical centre

The typical layout of a centre is illustrated in Figure 3. The particles are injected from a small linear accelerator and further accelerated to higher energies around the synchrotron, then extracted and delivered selectively to different rooms; the beam switching time between rooms is

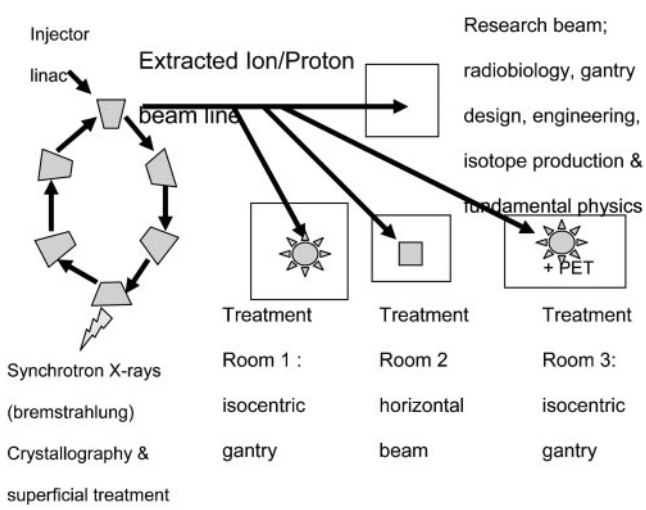


Figure 3. A schematic diagram of a synchrotron treatment centre.

as short as 10–20 s. A high throughput of patients can be achieved by efficient placement and preparation of patient position in advance of the beam availability in each room. Larger synchrotrons can deliver carbon ions or protons. Some rooms may be equipped with positron emission tomography (PET) scanning facilities and other image guided devices. The overall arrangement is quite different from standard radiotherapy departments where there is a linear accelerator in each treatment room. For more detailed plans see various chapters in Supplement 2 of *Radiotherapy & Oncology* (volume 73), 2004 [10].

The dose distribution advantages

Many authors have made important contributions by means of comparative dose distributions using X-rays and protons, which are summarized elsewhere [6, 7]. The essential principles may be better realised by inspection of relatively simple depth dose diagrams as seen in Figure 4. In Figure 4A, the spread out Bragg peak (SOBP) is seen from a single beam entering from the left hand side. In contrast, the X-ray fall off of dose is pseudo-exponential as shown in Figure 4D. When two opposed fields are used there is approximately uniform dosage in the case of X-rays (as in Figure 4E), whereas for particles there is a preferential dose deposition where the SOBPs coincide, as in Figure 4B. For three intersecting beams, there is now some degree of selectivity for X-rays as seen in Figure 4F, but the ratios of dose in the centre to that near the surface is considerably better for the particles as shown in Figure 4C.

Inspection of axial views of three intersecting beams, as in Figure 5, shows the different dose distributions achievable. These figures can be normalized to give the same dose in the central region, with resulting lower peripheral doses for particles. The absence of dose in one direction beyond the target is striking – this arrangement may be used to reduce exposure to critical structures such as

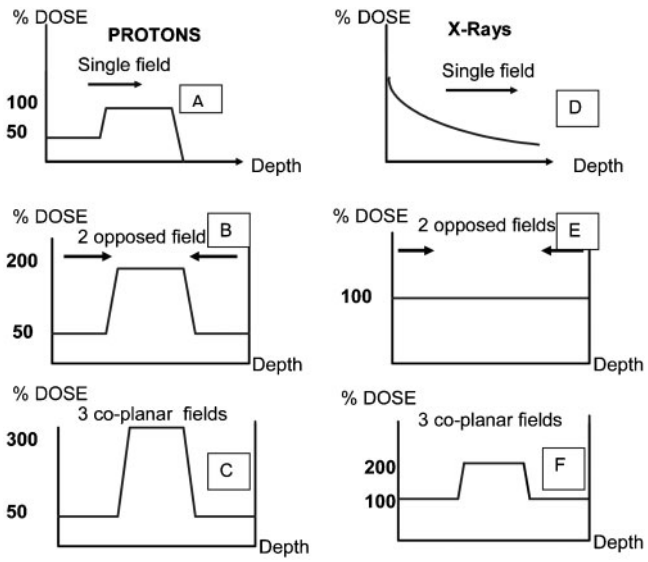


Figure 4. (A–C) Simplified schematic diagrams of protons and (D–F) X-ray percentage depth dose distributions for three simple field arrangements. In B, C, E, F depth is measured along the direction of opposing fields. Relatively small changes in dose are not included in these fields.

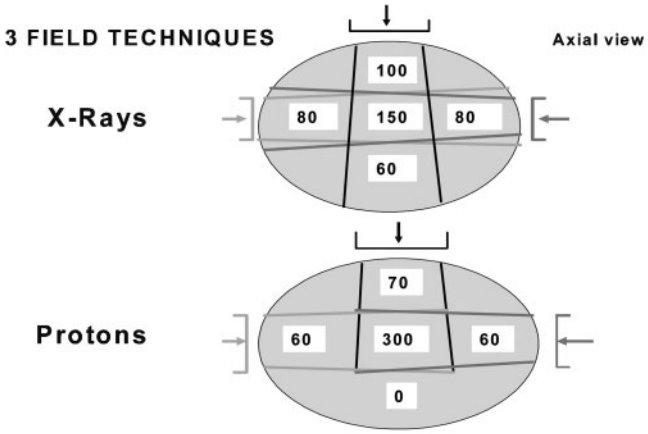


Figure 5. (a,b). Axial views of simplified schematic dose distributions for three field coplanar techniques using X-rays and protons.

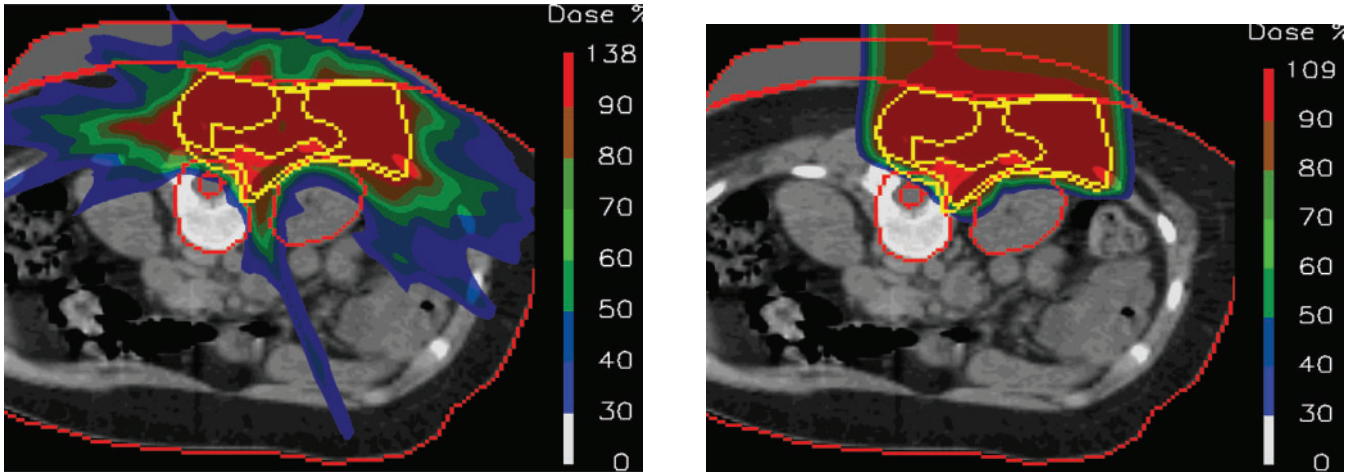
rectum, spinal cord, etc. Rotation of the beams may also be used to avoid beam traversion through, or scattered radiation from metal prostheses, which cause dose uncertainties in treatment planning.

The reduction in the so called integral dose, which is an assessment of dose to wider volumes within a patient, is considerable – proton beams generally reduce this by 50% and frequently by more in some cases [7]. This effect alone should reduce the risk of second cancer formation [8], which may be enhanced with the use of some modern linear accelerator based techniques such as intensity-modulated radiotherapy (IMRT), where there is a "dose bath" effect due to increased integral dose. Not only is the risk of second cancers reduced, but also substantial reductions occur in dose commitment to organs that are sensitive to radiation, *e.g.* kidneys, eyes, lung, heart, and parts of the nervous system. Low doses to substantial proportions of these organs can cause functional problems. For example, consider the treatment plans shown in Figure 6, where multiple field IMRT is compared with single field spot scanning protons. Whilst the target volume is covered equally well with both techniques, the dose bath effect is readily seen for IMRT, with significant dose to spinal cord and kidneys; the proton plan effectively spares these critical organs. Even a tissue such as bone is highly relevant: bone marrow cell production is not supported at doses above 30 Gy and longer term effects include osteoporosis, micro-fractures and fractures; in practice, low backache is not infrequent following pelvic radiotherapy, and bone density changes, revealed by MRI, are seen to exactly correspond to the beam portals used.

For a wide variety of cancers the advantages of the improved dose distributions should provide substantial improvements in the quality of life where normal tissue doses are reduced and improved cure potential when tumour dose is increased. These are considered in further detail in Table 1, although the generic reduction of second malignancy is not included.

Meticulous studies in Japan, using carbon ions, with respiratory movement gating compensation, have shown two extremely important results. They are:

(1) Cure of small peripheral screen detected lung cancers in a single exposure and without loss of lung function; similar



(a) (b)

Figure 6. (a, b) Comparative dose distributions for IMRT and protons for a recurrent sarcoma in a young 12-year-old boy (reproduced by kind permission of Dr A Lomax, PSI, Switzerland and Prof. P Hoskins, Editor of *Clinical Oncology*).

Table 1. The advantages of charged particle therapy (CPT) in a range of anatomical situations

Cancer bearing region	Advantage of CPT
Breast	Avoid irradiation of heart, lung and brachial plexus
Head and neck	Reduced dose to spinal cord, salivary glands, eyes, bone and brain
Pelvis (*e.g.* prostate, bladder, rectum)	Reduced irradiation of bone, sparing of organs such as bladder, rectum; large sarcomas are safely treated without sacral plexus damage
Gynaecological system	As in pelvis, but also improved dose to lateral parametrium, better distribution for vulvar cancers; can be used where brachytherapy not feasible; field extension to para-aortic region with less toxicity
Limbs	Reduced lymphoedema and deformities
Lung	Better preservation of lung and heart function
Liver/pancreas	Marked reduction in acute effects, can safely dose escalate for radio-resistant cancers, *e.g.* hepatoma, cholangiocarcinoma
Paraspinal/para-aortic	Sparing of small bowel, spine and kidneys
CNS	Reduction of irradiation to sensitive structures such as hypothalamus, pituitary, reduced risk of stroke
	Reduction of collateral irradiation to tissues outside the CNS, *e.g.* all tissues anterior to spine and reduced irradiation of appendages *e.g.* external auditory apparatus and eye, etc.

cure rates can be achieved by surgery, but with inevitable loss of lung function [9].

(2) Cure of patients with primary liver cancers treated in four exposures; again similar rates of cure can be achieved following surgery but with considerable morbidity and some mortality [10].

These results suggest that radiotherapy might eventually replace radical surgery in deeply situated anatomical locations. The risks and costs of radical surgery are likely to increase with time in an ageing population. In addition, these results confirm previous theoretical predictions based on radiobiological modelling that as dose is better localized to the target and markedly reduced in a wider range of surrounding tissues, the principles of fractionation become less important [11]. Thus treatment can be delivered in far fewer exposures; the economics of CPT then become more favourable. In addition, the treatment is more elegant, involves fewer beams and is potentially less liable to errors made in treatment delivery.

Owing to space constraints it is only possible to show a limited number of treatment plans. Figure 7 shows the advantages of a four field proton plan which could be used to treat a hepatoma or cholangiocarcinoma. The colour wash dose distribution shows how restricted the dose is to target; this spares the patient the acute side effects of nausea, vomiting and severe malaise which occur with X-ray traversion of the stomach, duodenum and liver.

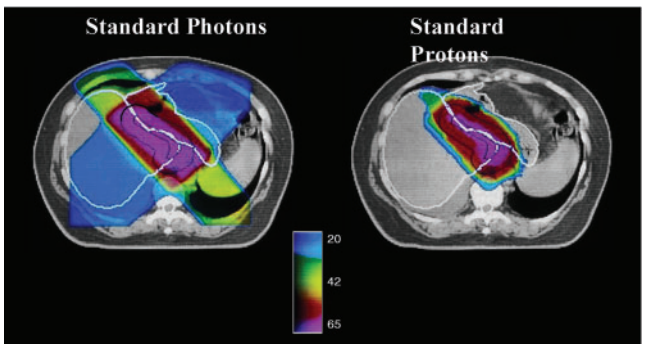


Figure 7. Comparisons of dose distributions for a 4 field X-ray (photon) plan and a proton plan for treatment of hepatocellular cancer (courtesy of Dr J Munzenrider, Northwest Proton Therapy Centre, Boston, USA).

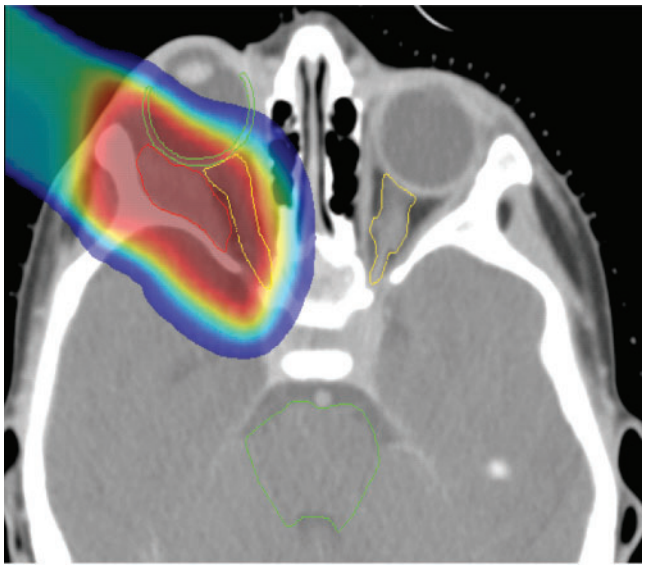


Figure 8. An example of a single field application of protons to treat a posterior orbital cancer (courtesy of Dr J Munzenrider, Northwest Proton Therapy Centre, Boston, USA). The colours denote different dose levels with red being the full prescribed dose, with fall off to the limits of the beam.

The next example (Figure 8) shows how the brain and other bony structures in the head and neck can be spared due to the sheer elegance of a single field proton approach to treat cancers in the posterior orbit, such as lachrymal gland cancer or rhabdomyosarcoma. To obtain equivalent uniformity of dose across the target region, at least 2 or 3 X-ray fields would be required, with resultant exit doses into the brain.

The existing evidence base

The clinical evidence base consists of phase I/II dose escalation studies. There are no randomized control trials that compare CPT with conventional radiotherapies [6], although there are randomized phase II "dose searching" studies. One example is the randomization between 72 Gy and 78 Gy cobalt Gray equivalent (CGE) for skull base chordomas at Massachusetts General. Some international authorities consider that randomized studies that compare conventional X-ray therapy with protons are not justified because of the advantageous dose distributions for the latter [12]. Whereas this may be true for skull base tumours and in hepatic cancers, there must be greater justification elsewhere, *e.g.* the comparison of IMRT/implants with protons in prostate cancer. Whether phase III studies (comparisons with conventional radiotherapy) will be performed remains to be seen: some authorities consider that such research would be unethical [12]. It is inevitable that randomized comparisons of CPT against radical surgery will have to be done for small screen detected cancers in deeply situated tissues (see below).

Misconceptions

It is not surprising that misconceptions abound when referring to CPT. Comparisons are often made with neutrons due to their production from similar sophisticated equipment. It must be remembered that neutrons are neutral particles and consequently do not have Bragg peak characteristics: the additional toxicity seen with neutron therapy was due to the higher relative biological effect (RBE) and high integral doses.

Precision is another issue: are protons and ions too precise? Certainly, the dose can be painted onto any safe volume, so that tumour margins can be fully respected. There is no reason why, in certain tumours, one cannot do wide initial volumes, shrinking down to smaller targets with increasing dose; protons could be used with three definite dose volume regions, *e.g.* 55 Gy, 65 Gy and 75 Gy volumes defined around a target simultaneously.

Many oncologists assume that the advantages are only seen in tumours such as skull base chordomas. It must be realised that such tumours were treated because of poor results with conventional therapy and with limited proton beam time coupled with relatively low energy beams that precluded treatment of deeper structures. Greater beam availability has allowed testing of CPT in a wider variety of tumours in different locations.

Added value for science research and teaching

A clinical facility could also be used for radionuclide production: the particles can activate stable elements to become radioactive, with applications in healthcare and industry. Overnight production allows income generating use of short-lived radionuclide on the following day.

Synchrotron radiation, essentially mono-energetic bremstrahlung emitted when the particles are deviated by magnets, can be used for X-ray crystallography studies. Particle micro-beam analysis of solid state and biological material can also be pursued, *e.g.* intracellular diagnostic capacity at nanometre levels, testing of materials for their resistance to cosmic rays prior to space flights. A detailed case is presently being written by the Engineering and Physical Sciences Research Council (EPSRC) Medical Applications of Ion Beams Network.

Contributions from molecular biology

The vast expansion in knowledge gained by research in molecular biology applied to oncology will inevitably result in more reliable early diagnosis of cancer. Screening of a population by "PCR (polymerase chain reaction) amplification" techniques and proteomic techniques should detect aberrant DNA and protein products from quite small cancers in body fluids. Further gene specific or target protein imaging using sophisticated forms of PET scanning may be sufficient to confirm the presence of small cancers in deeply situated organs. Image guided biopsies may also be necessary in some cases. These approaches are probably more practical than the more distant Holy Grail of cancer cure following the application of such approaches. This is not to say that such approaches will not be useful, particularly in modifying cancer growth patterns and metastatic potential; but when used alone, molecular approaches may be doomed to failure because of the capacity of a cancer to produce further mutations and to bypass metabolic blockade even when multiple approaches are used. However, the reliable earlier diagnosis of cancer would create a high demand for

surgery and radiotherapy, particularly highly focal forms of radiotherapy that enable a high localized dose to be delivered with good sparing of normal tissues, as in CPT. The decisive clinical trials of the future may be those that compare CPT with surgery, particularly in sites where the latter has a high morbidity, mortality and cost, *e.g.* hepatic, pancreatic and renal surgery.

Contributions from medical oncology

The reduction of exit dose radiation to skeletal regions that contain active bone marrow will reduce the risk of severe neutropenia and the morbidity and mortality that follow septicaemia. Thus CPT radiotherapy may be combined with more aggressive chemotherapy regimens. In addition, the risk of subsequent organ failure on exposure to certain classes of radiotherapy may be reduced. For example, the cochlear sparing associated with medulloblastoma proton-therapy is likely to reduce the high tone deafness associated with the use of Cis-platinum treatment [13]; the risk of renal failure may be reduced when using protons instead of IMRT to treat the para-aortic nodes in metastatic or advanced local cervix cancers. Also, the risk of severe cardiomyopathy may be reduced – even in the case of later exposure to anthracycline drugs – if the heart has not been exposed to significant radiation dose by use of CPT, *e.g.* in the case of left sided breast cancer. There is clearly a wide prospectus for research with a major input from medical oncologists with an interest in radiotherapy in this important area of oncology.

Contributions from surgery

The increasing future role of radiotherapy in small volume deep-seated cancers has already been mentioned. For larger cancers, volume reduction using surgery may still be desirable, as might the concept of ''improving treatment geometry'' by selective resection and restoring a finite space between tumour and critical normal tissues. Prolonged surgery will always reduce tissue tolerance owing to accumulated vascular damage. Decisions regarding operability, the extent of surgery and the necessary dose of radiation will always need careful consideration according to circumstances. The possibility of pre-operative CPT in some situations would be useful: in Massachusetts General Hospital there is already some experience of pre-operative proton therapy to paraspinal bone tumours in order to reduce the potential for brachytherapy catheter implantation of tumour cells when radio-iodine seed implants are made into the adjacent bone situated distally to the tumour. There is clearly considerable scope for research in the degree to which surgery and CPT can be combined.

Research and development: quality adjusted survival end points

There is increasing disquiet that very large trials are required to detect small incremental changes in outcomes, with a tendency to favour patient survival as the primary end point, possibly with inclusion of some separate quality of life study. This stance is not unreasonable for comparisons of chemotherapy schedules, where severe acute toxicity is life threatening and influences survival. Such approaches are far from ideal for the assessment of new radiation techniques where subtle long-term differences in a wide spectrum of tissues are more relevant. Newer forms of trial assessment will probably be necessary. One such approach is considered here. In a computer generated survival curve with only 100 patients in each treatment arm, with a survival advantage of $\sim$10% for CPT *c.f.* X-rays, the p-value exceeds 0.05 using the log-rank test ($p>0.05$). The side effect profiles (graded in four categories according to ascending severity) show subtle improvements with CPT, although when tested using a contingency table the Chi-squared statistic shows a non significant trend ($p>0.05$) because of the low numbers in each category. But when survival is adjusted by using the toxicity grade factor F defined as $(5\text{-}x)/5$, where x is the toxicity grade with five categories, the quality adjusted survival (F times the actual survival) becomes highly significant ($p<0.0001$). More work is required to justify and encourage these approaches, but the potential advantages in terms of cost and rapidity of obtaining results with a greater number of trial arms containing different doses/treatment combinations are readily apparent from the example given. Such a novel approach could be used within CPT studies.

The threat to British oncology

If the UK will not invest sufficiently rapidly in CPT facilities, there is a real risk of there being between 5000 and 12 000 patients who will require or demand therapy abroad in around 10 years from now [14]. These estimates were arrived at using the logistic equation to simulate supply and demand with best and worst case scenarios for overall capacity to accept UK referrals abroad. Treatment abroad would undoubtedly cause severe disruption of multidisciplinary cancer care as well as anticipated social and linguistic problems. In terms of staff retention, there is a risk that many British physicists, radiographers and oncologists might be attracted to work abroad. Also, the UK clinical trial portfolio may not contain state of the art radiotherapy and consequently our trials may become irrelevant and ignored elsewhere in the world.

Costs

It has become politically incorrect to mention costs in medical circles, although cost effectiveness is deemed respectable and quotable. Such restrictive criteria are, for example, accepted by *The British Medical Journal* for its publications. One cannot escape the fact that the costs for synchrotron commissioning are large, of the order of £70–100 million depending upon the specifications for protons and the more expensive ions and how many large gantries are required. Some consideration has already been given to cost benefit and patient demand in Switzerland, Sweden, France and Austria [15–18]. Cost benefit will be most accurately measured prospectively within clinical trials. The costs charged will vary with the number of exposures: presently around £12 000 for 4 exposures at Clatterbridge; but with some economies of scale and improved throughput one can envisage CPT for around

£8000–25 000 per patient, depending on the fractionation used; this is less than the cost of renal dialysis necessary to keep a patient alive for 1 year and compares favourably with the cost of prolonged radical surgery.

A single UK centre should recoup its own initial and running costs within 6 years providing it can treat 2500 patients by its third year of operation. However, the UK would depend on a multitude of healthcare purchasing agreements – a most unsatisfactory system for the provision of complex healthcare. Definitive cancer treatment using radiation should be separated from these cumbersome procedures, with a clear assurance that all British patients with a diagnosis of cancer will receive equal access to more complex therapy where necessary.

Dr Neil Burnet has estimated from Swedish data (Burnet N, personal communication) that the proportion of total cancer care costs spent on radiotherapy would increase from the present 5% to 6% if 15% of all radiotherapy is given by protons [18]. This is likely to be cost effective in the long term because of the reduced side effects and compares well with the present expenditure on cytotoxic chemotherapy, which accounts for around 12% of total cancer care.

It remains unclear as to how funding can be achieved without a high level political decision. Even the new Foundation NHS Trusts cannot borrow the necessary monies to enable CPT. Our NHS needs better structures that can arrange finance, whether public or private: perhaps a return to regional and supraregional systems for cancer care?

Logistics for a National Centre

The NHS has developed impressive Cancer Networks as part of its Cancer Plan, and CPT will need to be imaginatively superimposed on this framework. These existing networks are essential to ensure equity of access for CPT. Each local Network should form the basis of referral to special multidisciplinary team (MDT) meetings concerned with CPT. When a clinical indication is identified, then appropriate dose planning assessments are necessary: this might be achieved by electronic transfer of data to a national reference centre which itself might be virtual, *i.e.* it can be envisaged that all cases of tumour type X might be independently assessed in City A, and for tumour type Y in City B as for the physical appropriateness of IMRT or CPT. The referring city could also plan with the two modalities and confer with the national CPT centre. Encouragement for physicists and oncologists to attend a National Centre on a rotational or frequent basis, *e.g.* for specific MDT and treatment planning meetings, should also be encouraged. A national service will need to have strong links with other centres abroad for the treatment of rare conditions.

Logistics for referral abroad

The prospect of referring hundreds or thousands of patients abroad is daunting. The time taken to assess and counsel, and to send all diagnostic information away is significant. There is an immediate need for full time staff devoted to these logistics, with attention to transfer funding for provision of appropriate care abroad. British staff should be put in place to support patients and families whilst abroad and also to promote training in how to deliver CPT. Eventually, the number of treatment facilities in the UK should become appropriate to meet the needs of the British people. However, UK healthcare planners should urgently apply themselves to these problems and produce appropriate plans that meet the most likely short and long-term requirements.

Politics/Government/Research Councils and Charities

CPT needs to be fully researched, with major UK participation. At least one high-energy UK CPT facility should be established to conduct clinical research and trials, with equitable patient referral via the Cancer Networks. The immediate questions for the UK authorities are ''when'' and ''how many facilities'' do we need? These important decisions confront the UK Government for future cancer care, and must be judged in the context of the proposed increased investment in the scientific base of this country [19]. The concept of joined up working across the various Research Councils (EPSRC, MRC, Accelerator Science, N-Tech), and linked to the major cancer charities (Cancer Research UK) should allow the UK to further develop the technology that underpins the most sophisticated form of radiation therapy against cancer. It would be tragic to wait until public awareness forces the issue. Bevan, an astute politician and cancer sufferer, would surely have sensed that the NHS should possess the weapon of particle radiotherapy within its arsenal against cancer, in the same way as he bravely supported an independent nuclear deterrent. He wanted only the best for the British people and so should we.

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